Chapter 9

Toward a Sustainable New York City: Greening through Urban Forest Restoration

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> The city, suburbs, and the countryside must be viewed as a single, evolving system within nature, as must every individual park and building within the larger whole. . . . Nature in the city must be cultivated, like a garden, rather than ignored or subdued.
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> —Anne Whiston Spirn, *The Granite Garden*, 1984

On Earth Day 2007, New York City Mayor Michael Bloomberg announced PlaNYC, a long-term vision for making New York City more sustainable by 2030.[1] PlaNYC creates a long-term urban-planning mission for NYC that has sustainability at its core with a triple bottom line set of goals: to simultaneously improve the urban environment, economy, and overall quality of life. The ambitious 127 initiatives range from revamping aging infrastructure to making sure that all city residents live within a ten-minute walk of a park to cutting greenhouse gas emissions by 30 percent by 2030. One of the most visible initiatives is MillionTreesNYC, a plan to add 1 million trees to city streets, parks, and private land by 2017.

PlaNYC has gained tremendous attention both nationally and internationally since its inception and has been acknowledged around the world as one of the

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most ambitious—and most pragmatic—sustainability plans anywhere. However, it remains to be seen how much of the plan will ultimately be enacted and whether the planned environmental, economic, and social benefits will be fully realized. This chapter will explore the sustainability goals and predicted environmental risks for NYC with a focus on the potential solutions provided through one of the most publicly visible and successful of PlaNYC's sustainability initiatives, MillionTreesNYC.[2]

Greening New York City

Despite NYC's towering buildings, congested streets, and often questionable air quality, the Green Apple is still one of the most sustainable cities in the country.[3] NYC's current status as a relatively green city is primarily due to its high density, walkability, and extensive transit system. Its age and restricted coastal geography have helped to generate a dense, compact living environment. While New Yorkers will be the first to tell you that the city has a long way to go to become truly green, the city's per-capita emissions are a third of those in the rest of the country and its famous subway transit system is at a fifty-year high in ridership. In fact, NYC trails only Tokyo, Seoul, and Moscow's subways in annual ridership, and easily carries more passengers than all other rail mass transit systems in the United States combined.[4] Cleaner energy supplies are aggressively being planned and built, tax credits for solar power are some of the best in the country, and the mayor has recently been pushing for installation of offshore wind turbines. And with PlaNYC, these and many other urban improvements are now captured within a unifying plan for the city.

Efforts to improve the sustainability of New York City did not begin with PlaNYC. In the 1950s and 1960s, pioneering New Yorkers and other urbanites began outlining the ways in which NYC could encourage healthier, cleaner, and more sustainable modes of living. New York City owes its current sustainability vision to the foundations laid by works such as William Whyte's seminal book, *The Exploding Metropolis*, Jane Jacobs's *The Death and Life of Great American Cities*, and Ian McHarg's *Design with Nature*. Since then, a small but growing minority has continued to vocalize the need for greening NYC. Modern threats such as climate change have only served to rally a larger and larger citizenry to lobby, protest, and work diligently to build the kind of future plan for the city that is embodied in the best of PlaNYC's intentions.

In addition to government action, the city boasts a number of grassroots and neighborhood organizations working to green the city. Indeed, in a recent study by the U.S. Forest Service, researchers found well over 2,000 NYC-based civic environmental groups that describe themselves as actively involved in stewardship.[5] Sustainable South Bronx is one of the most successful and well known of these. The group, centered in a low-income borough of the city, is helping to revitalize parks, improve greenways, install green roofs, and provide green job training. Other nonprofits like the Lower East Side Ecology Center, Solar One, the Hudson River Foundation, New York Restoration Project, and many others are working to improve both the terrestrial and aquatic environment in the city. Current efforts include urban farming programs to increase the local food supply, painting roofs white to decrease the urban heat island effect, green roof installations, expanding farmer's markets through the Green Market program, revitalizing local oyster populations through ecological restoration, and a host of environmental education programs throughout the city.[6]

New York City's relatively high position in the hierarchy of "green" cities is due to another important piece of history. Specifically, this is Frederick Law Olmsted's transformation of the city into urban parkland through signature works such as Central Park in Manhattan and Prospect Park in Brooklyn. These and many smaller parks provide the city with the rich green infrastructure resources upon which further greening continues today. The country's largest metropolitan area is a highly complex human ecosystem. The city has a wide variety of natural environments and habitats, including 29,000 acres of parkland—11,000 acres of which are still natural—ranging from beaches and rocky shorelines to freshwater wetlands, salt marshes, meadows, and forests.[7] It also has a large urban forest, including trees growing in city parks, on private land, and along city streets. It is crucial that the city efficiently uses and expands ecological amenities like these as it seeks to meet the environmental, economic, and social challenges confronting it.

Urban Climate Challenges

New York City faces a number of modern environmental challenges, some of which affect cities generally and others that are unique to the NYC metro region. The increased heat in the urban core—otherwise known as the urban heat island effect (UHI)—is a challenge in most cities and can be dramatic, with

temperatures between the urban cores and their surrounding suburban areas differing from 2 to 22°F. The UHI occurs when the city is significantly warmer than its surrounding rural areas and is usually most pronounced at night.[8]

Trees and other types of green infrastructure are well known tools for offsetting the UHI. Figure 9.1 demonstrates the strong correlation between cooler temperatures and the presence of trees in NYC. The cooling effect of the extensive tree canopy cover in the surrounding areas and in the parkland within NYC can, of course, be measured, but it can also be *felt* when compared to the intense heat capture of the pavement and buildings in downtown Manhattan. It is now standard procedure for cities to plant trees and install green roofs to mitigate urban heat.[9] For example, Los Angeles, Chicago, Denver, and Austin all have citywide programs to plant a million trees, similar to the NYC initiative. Chicago in particular has been a national leader in the use of green roofs for urban cooling. The flagship green roof there is the 20,300 square foot rooftop garden atop Chicago's City Hall that has more than 20,000 herbaceous plants of more than 150 varieties including 100 woody shrubs, 40 vines, and 2 trees.

Global climate change provides a significant challenge that is already beginning to threaten parts of the city. Formed by New York Mayor Michael Bloomberg in 2008, the New York City Panel on Climate Change issued a report in 2009, which shows that the city is vulnerable to rising sea levels, flooding from increased precipitation, and more extreme weather events such as heat waves.[10] A comparison of global climate model simulations for NYC shows that climate change is extremely likely to bring warmer temperatures to the city and the surrounding region, causing more hot days, hotter summers and warmer winters, higher sea levels, more frequent and intense coastal flooding, and more frequent and intense heat waves.

It is possible that the predicted effects of climate change are already being felt. Urban forests in NYC recently suffered from a couple brief but intense storms of the type described in the recent climate risk analysis. In August of 2009, a fierce rainstorm with high winds tore through the city, toppling more than 100 trees in Central Park and damaging many others. Adrian Benepe, the city parks commissioner, said "It created more damage than I've seen in thirty years of working in the parks."[11]

Just eight months later in April 2010, after days of steady rain saturated the ground across the region, a brief but heavy windstorm with hurricane-force winds blew through the metro area. The effects were so severe in some places

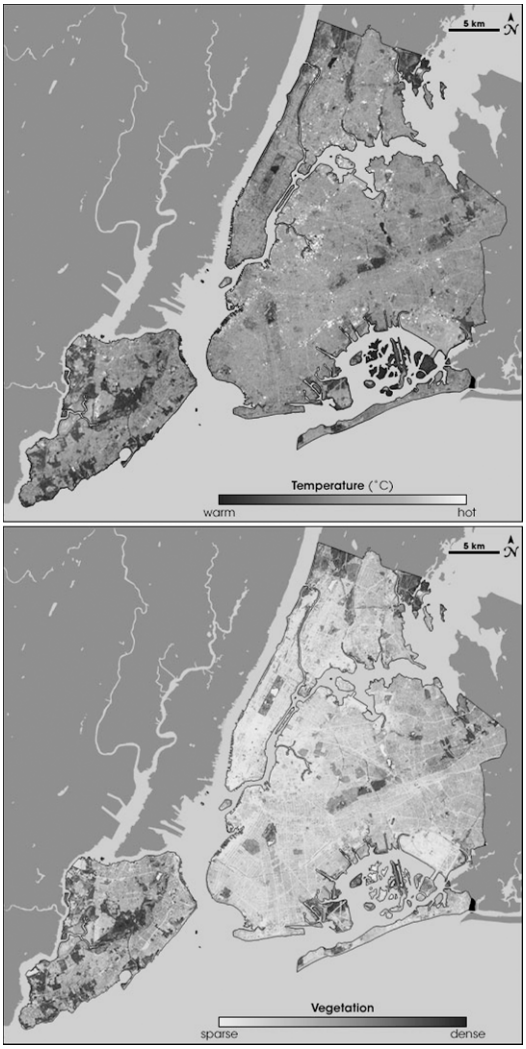

Figure 9.1. Urban Trees Mitigate Urban Heat: The potential mitigating effect of the urban forest on the urban heat island is shown in these two comparison satellite images measured by NASA's Landsat ETM+ on August 14, 2002, one of the hottest days in New York City's summer. The Landsat ETM+ satellite also collected thermal infrared data for heat and vegetation data at the same time. The coolest areas during this heat wave correspond to areas with the most vegetation. The top map shows temperature, with cooler temperatures appearing in darker shading and hotter temperatures appearing in lighter shading. The bottom image shows vegetation, with lighter shading indicating sparse vegetation and darker shading indicating dense vegetation. The maps show a correlation between dense vegetation and cool temperatures and between sparse vegetation and high temperatures. Maps were created by Robert Simmon of NASA Earth Observatory, using data from the Landsat Program, and can be accessed at http://earthobservatory.nasa.gov/Features/GreenRoof/greenroof2.php.

that it looked as if a tornado had touched down. The local power company officials at ConEdison said that the storm damage was the worst in thirty years. Kevin Law, president of the Long Island Power Authority, said that the storm was "among the top five or six weather events that have impacted Long Island in the last forty years."[12]

In the days following the April storm, the city parks department found that more than 1,100 street trees had fallen or split and 25 city parks crews had to be dispatched to investigate reports of trees crashing into 117 homes. By the time the worst of the weekend storm was over, at least six people were killed, countless vehicles and homes were smashed, scores of roadways were left impassable, and more than 500,000 homes had lost power (many of which stayed without power for weeks). Recent data from global climate models suggest that NYC will be in for more of these intense storms, which likely means more havoc to manage for the NYC Department of Parks and Recreation and more destruction to the critical green infrastructure of the city. The recent economic downturn and budget cuts across the city have affected the parks department right when it is in need of *increased* resources to manage the needed ecological infrastructure upon which so much of PlaNYC and the city's future depends.

In the last few years the general public has become increasingly aware that rising sea levels, caused primarily by glaciers melting globally and rising ocean temperatures causing them to expand, pose a serious potential threat to the economy and ecology of NYC. More than 62 percent of the city's population lives in marine coastal counties. The Northeast Climate Impacts Assessment conducted by the Union of Concerned Scientists in 2007 concluded that as seas rise, beaches and bluffs will suffer increased erosion, severe flooding and storm damage will increase, low-lying areas will become inundated with potential for saltwater to infiltrate into surface waters and aquifers, and sewage and septic systems as well as transportation infrastructure will be at risk of flooding and erosion.[13]

Globally, sea levels are currently rising on average about one tenth of an inch per year. In the New York–New Jersey Harbor area, sea level is projected to rise up to 12 inches by 2050. In addition, droughts may also become more severe, which could affect urban ecosystems and the services they provide to New Yorkers. These types of short-duration climate hazards can pose particular threats to both built infrastructure and natural ecosystems . . . and they will affect every New Yorker.

After reviewing the climate-risk information, Mayor Bloomberg declared climate change the "biggest challenge of all" facing the city. To develop responses, both mitigating and adapting to climate change, we need to ensure that we plan the city in ways that increase our climate resilience. PlaNYC is relying heavily on green infrastructure such as NYC's urban forest to protect local waterways from stormwater runoff while utilizing "green streets" and new storm water capture designs beneath green traffic islands to reduce the predicted increases in runoff. If PlaNYC is to be successful, it must dramatically transform the city to mitigate our impact and adapt to these threats.

PlaNYC 2030

One of the primary motivations for PlaNYC is the realization that by 2030 an additional nearly 1 million people will reside within city boundaries, growing from 8.36 million today to roughly 9.1 million in 2030. New York is already the largest and most dense metropolitan area in the United States.[14] Planning for this challenge requires NYC to build new affordable housing while it also goes through a serious rezoning effort to further direct growth. The challenge of addressing threats from climate change and other environmental issues while accommodating a growing population is what led the Bloomberg administration to set the ambitious goals in PlaNYC. The PlaNYC 2030 goals include seeking to:

- Create homes for almost a million more New Yorkers while making housing more affordable and sustainable
- Ensure that all New Yorkers live within a ten-minute walk of a park
- Clean up all contaminated land in New York City
- Open 90 percent of waterways to recreation by preserving natural areas and reducing pollution
- Develop critical backup systems for the aging water network to ensure long-term reliability
- Improve travel times by adding transit capacity for millions more residents, visitors, and workers
- Reach a full "state of good repair" on New York City's roads, subways, and rails for the first time in history
- Provide cleaner, more reliable power for every New Yorker by upgrading the energy infrastructure

- Achieve the cleanest air quality of any big U.S. city
- Reduce global-warming emissions by more than 30 percent

Successes so far include a 2.5 percent reduction in citywide greenhouse gas emissions between 2005 and 2007, conversion of 15 percent of the taxi fleet to hybrid vehicles, and construction on the largest UV disinfection plant in the northern hemisphere to treat more than 2 billion gallons of drinking water a day. The city has also installed 141 miles of bicycle lanes and 1,211 new bicycle-parking racks, part of a bike master plan to provide 1,800 miles of bike paths throughout the city.[15] One of the most visible successes of the plan is the planting of hundreds of thousands of trees, including tens of thousands of street trees—especially in low-income and poor-health neighborhoods—through the MillionTreesNYC campaign.

However, issues such as air quality remain a challenge in NYC. Poor air quality is increasingly recognized as a major public health threat. Despite decades of progress, the New York City metropolitan area is still rated one of the most polluted cities for exposure to fine particulate matter, ozone, and other air pollutants.[16] Air pollutants exacerbate respiratory and cardiovascular illness and contribute to hundreds of premature deaths annually. Improving air quality relies on reducing emissions but also on finding ways to absorb pollutants. Planting trees is a relatively low-cost tool for dealing with air pollution, while simultaneously investing in the physical green infrastructure that provides a host of other aesthetic and social benefits to urban dwellers.

Benefits of Trees

The list of ecological, economic, and social benefits that urban trees provide cities is quite long. Indeed, many of the city's plans to offset urban contributions to climate change count on the urban forest growing, maturing, and sequestering an increasing amount of carbon while cooling the city via thermoregulation. Trees can regulate local surface and air temperatures by reflecting solar radiation and shading surfaces, such as streets and sidewalks, that would otherwise absorb heat. Decreasing the heat loading of the city and thereby mitigating the urban heat island effect is probably the most important ecological service trees provide to cities. Trees also provide cooling to cities through evapotranspiration of water. Evaporated water leaves the plant as water vapor, absorbing heat as it evaporates

and rises, thus cooling the air in the process. A single mature, properly watered oak tree can evapotranspire up to 40,000 gallons of water a year.[17] If an urban area like New York City eventually adds 1 million additional trees to its urban forest, the total cooling effect could decrease the heat of the city by a full degree or more.[18]

Urban trees provide a direct ecological service to cities by reducing urban surface and air temperatures through both shading and evapotranspiration, yet the indirect effects of trees are just as important. For example, a cooler city leads to substantial reductions in energy use for air conditioning. The U.S. Forest service found that New York City's street trees provide an estimated $27 million a year in energy savings through shading buildings.[19] As decreased energy use translates into fewer emissions from energy supply sources, it could also improve stability in the energy supply during peak uses, such as summer heat waves. Trees also provide shade for roads and parking lots, which would otherwise become very hot during the day and which store heat for later release at night. Shading of vehicles in parking lots can reduce evaporative emissions from gasoline, which contributes to increased levels of urban ozone.

Urban trees, like all trees, help offset the root causes of global climate change by capturing and storing atmospheric carbon dioxide in their leaves, stems, and roots. The U.S. Forest Service (USFS) has been actively studying the benefits of urban forests and found that NYC's trees store about 1.35 million tons of carbon valued at $25 million. In addition, NYC's trees remove another 42,000 tons of carbon each year. The soils that support trees also remove carbon dioxide from the atmosphere and absorb water. Similarly, urban trees capture rainfall on their leaves and branches and take up water through their roots, acting as natural storm water capture and retention devices. Storm water capture is a major issue in cities, and one of the major goals of PlaNYC is to improve it in order to prevent pollution loading to local waterways. Street trees in NYC intercept almost 900 million gallons of storm water annually, or 1,500 gallons per tree on average. The total value of this benefit to New York City is more than $35 million each year.[20]

Improving air quality by removing dust and other pollutants from the air is another primary benefit of urban trees. In fact, one tree can remove 26 pounds of carbon dioxide from the atmosphere annually, the equivalent of 11,000 miles of car emissions. NYC trees remove about 2,200 tons of air pollution per year, valued at $10 million annually.[21] There is growing evidence that trees help reduce air pollutants that trigger asthma and other respiratory illnesses. To find out how

air quality relates to human health the Department of Health and Mental Hygiene (DOHMH) launched the New York City Community Air Survey (NYCCAS) in December 2008 to measure the variation in concentrations of street-level pollutants at 150 locations during every season of the year.[22] Though links between human health and air quality are still being studied, MillionTreesNYC has targeted its initial tree plantings in areas with high asthma rates, the expectation being that spending money on trees could be one of the highest-return investments in public health. Trees also provide about 60 percent blockage from the sun's rays, thus reducing overexposure to UV radiation, the primary environmental risk factor in the development of skin cancers and other diseases.

Economically, trees provide an important return on the significant investment cities make in their care and planting. In NYC, trees provide approximately $5.60 in benefits for every dollar spent on tree planting and care, dollars that would otherwise be spent on energy for cooling and storm water retention services.[23] They also increase property values, as homes are worth more when they are next to parks, green belts, or other green spaces. Additionally, the greening of business districts can increase community pride and positive perception of an area, drawing customers to the businesses.

MillionTreesNYC

The potential for the urban forest to simultaneously reduce the effects of climate change and mitigate the urban heat island effect, while also improving the quality of life of New Yorkers, eventually made it obvious to city officials to put significant resources toward increasing the green infrastructure of NYC. MillionTreesNYC (MTNYC), a campaign to plant 1 million trees in NYC by 2017, is regularly lauded as one of the most important and most successful initiatives in PlaNYC. At the beginning of the campaign, the Department of Parks and Recreation initiated a strategy of full-block planting to rapidly green entire neighborhoods, with a target in the first years on low-income areas with few trees and high asthma rates (*Trees for Public Health*).[24]

MTNYC intends to fill every available street tree opportunity in New York City. To achieve these ambitious goals, the parks department allocated $400 million to the MTNYC campaign over ten years and developed a public-private partnership with the local nonprofit New York Restoration Project (NYRP). The ultimate goal is for the city to add 220,000 street trees and 380,000 park trees in a

massive forest restoration effort that will expand the city's forest by 2,000 acres, while NYRP coordinates planting 400,000 trees, working with private organizations, homeowners, and community organizations. In total, MTNYC will add 20 percent more tree canopy cover to the city.[25]

Since the launch of MTNYC in 2007, NYC has, through the New York City Department of Parks and Recreation, added 112 acres of new parkland, as well as improved access and amenities at existing parks and open spaces. Now in its third year, MillionTreesNYC has added to this effort by planting 350,000 trees, more than 35,000 of which are newly planted street trees (see figure 9.2 for a map of MTNYC tree plantings to date). Public, private, and nonprofit organizations have together rallied nearly 4,000 citizen volunteers to plant trees across the city in what has become an unprecedented tree-planting campaign and citywide environmental movement. But what will this extra tree canopy do for New Yorkers, other biological species, and the climate? Is the ecological pulse of

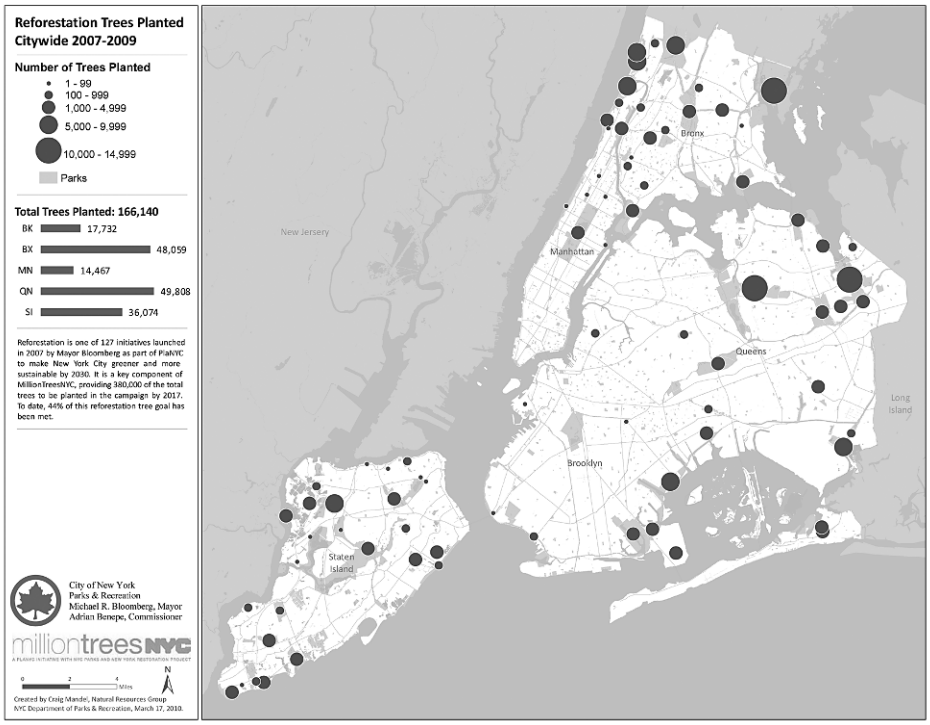

Figure 9.2. Recent results from MillionTreesNYC tree planting in parks, privately held land, along streets, and other areas around the city between 2007 and 2009. The image is taken from the MTNYC website at www.milliontreesnyc.org/.

added trees in a citywide tree-planting campaign sufficient to measurably increase long-term resilience and, therefore, sustainability in New York City's ecosystems? In the case of enlarging and restoring urban forests to make NYC more sustainable, many of the expected benefits of trees will not be felt until well after 2017 because trees need significant time to grow and mature. Indeed, it is not yet clear that planting trees will achieve the ambitious goals set forth in PlaNYC. The 1 million new trees must first survive the early years of city life in order to function as intended.

The Need for More Research

It is clear that trees are not simply landscaping agents in the city. Rather, they are major structural and functional elements in human terrestrial ecosystems. Trees are also homes to birds, mammals, invertebrates, and microbes, all of which perform additional important ecological services. However, urban environments are notoriously difficult places to live for many biological species. Urban trees suffer from a vast array of damaging pollutants, from acid rain washing over their leaves to being doused with bleach water as part of morning sidewalk cleaning routines. Road-salt application in the winter and prolonged heat spells in the summer can create extreme drought-like conditions for trees living in city streets. Street trees are particularly susceptible to stress due to the small spaces in sidewalks where they are forced to grow, their highly compacted and acidic soils, and the many injuries they suffer from living in such close proximity to urban life.

Young urban trees (less than 5 years old) are probably the most at risk with often-high mortality rates in New York City largely due to common urban stressors of heat, salt, and pollution, but also from lack of individual care during the first five years of their lives.[26] Forest restoration tree plantings in city parks and on degraded or existing parkland are typically small two-gallon container trees that are one half to one meter tall and one to two centimeters in diameter. MTNYC volunteers and contractors strategically plant these susceptible trees in the fall and spring months to avoid harsh drought conditions in the summer. However, expectations are that without adequate care, many of these trees will fail to survive the first year. With climate change predicted to increase the frequency of extreme heat events in NYC, newly planted young trees may ultimately fail to perform ecologically, economically, and socially as intended. Can the urban forest reliably function at the level urban sustainability campaigns such as PlaNYC ex-

pect and predict? What are the best planting strategies to maximize the many functional demands being placed on trees as urban environmental cleanup machines? These questions are still unanswerable, primarily because the study of urban ecosystems is new and as yet has not been able to provide adequate data for managers. We simply do not know what tree species will best meet the challenges of urban environments, or how best to design green spaces to maximize both desired ecological functions such as carbon sequestration and human functions including aesthetics and recreation. Similarly, it is difficult to know whether the current management practice of chemically and physically removing invasive species from city parks and planting trees in their place will ultimately change the structure of urban forests from invasive-dominated systems to multistory forests.

Ecologists, urban planners, and designers alike are asking: How do we simultaneously accommodate more urban dwellers and design cities as functional sustainable ecosystems? Clearly, there is a need for increased research in human-dominated ecosystems, New York City included. Though city officials and park managers are aware that evaluation of existing planting strategies and site designs are critical to the long-term success of the MTNYC campaign, providing mechanisms, incentives, and opportunities for research has been slow, even though the motivation exists among city government personnel. This is not surprising given the pressure put on small, often understaffed departments to deliver results, such as ambitious annual planting goals (~100,000 trees/year), in short periods of time.

At the beginning of the campaign, MTNYC created a Research and Evaluation Subcommittee of their advisory board. In conjunction with collaborators, including the New School, Cornell University, New York University, the U.S. Forest Service, and a nonprofit SoundScience, a workshop was hosted, MillionTreesNYC, Green Infrastructure, and Urban Ecology: Building a Research Agenda.[27] The workshop brought together nearly 100 researchers and practitioners to help MTNYC develop research priorities for evaluating the effects of MTNYC on the city ecosystem. One of the outcomes of this research workshop was a critical examination of the goals of MTNYC and the management strategies currently employed to meet them. The primary consensus from symposium participants was articulated in terms of a pressing need to understand urban ecosystems much better than we do. New York City, as such a system, is no exception.

The Study of Human Ecosystems

Though the study of urban ecosystems is still a relatively new pursuit in ecology, the contemporary ecological paradigm now recognizes that humans are an integral part of ecosystems, exerting direct and/or subtle influence on their functioning.[28] Though social scientists began contributing to a broader view of ecosystems that included humans during the 1950s along a continuum from wilderness to urban areas, cities remain an open frontier for socio-ecological research.[29] The need to understand the intricacies of urban systems is made obvious by the fact that an increasing proportion of humanity call cities home and also from the disproportionate impact cities have on regional and global systems. Among the many human activities that cause habitat loss, urban development produces some of the greatest local species extinction rates and can frequently eliminate a large majority of native species.[30] It is also clear that the increased energy use by humans in and around cities is another significant driver of changes in the way ecosystems function. At the same time, densely populated cities like NYC can be a net benefit to global ecosystems because they provide efficiencies that can limit the human impacts of more dispersed, resource-intensive settlement patterns such as sprawling suburbs. Ecosystem services, such as carbon uptake and thermoregulation by vegetation, can be promoted and managed in urban settings. These facts and more point to the need for a different manner of urban living and a more nuanced understanding of urban ecosystems in order to improve and adaptively use a combined socio-ecological theory to explain and predict urban ecosystem dynamics.

Urban ecology was first pioneered in Europe with the study of the succession of vegetation on ruins following World War II bombing sites in Berlin and other cities. Later ecologists began to study energy flow and nutrient cycling at the scale of whole cities in the 1970s.[31] The first on-the-ground research in the United States of cities as human ecosystems arguably began in NYC with the establishment of a long-term Urban-Rural Gradient Ecology (URGE) program in the late 1980s by Mark McDonnell and Steward Pickett.[32] It has taken the last couple of decades to develop the supporting theory and for different disciplines to learn to dialogue and collaboratively share data. Urban ecology has proceeded significantly in recent years primarily due to funding by the National Science Foundation (NSF) of two long-term ecological research (LTER) sites, Baltimore, Maryland, and Phoenix, Arizona, which are now producing important

empirical observations of the cities as ecosystems.[33] Though these two cities now dominate the current field of urban ecology in the United States, it remains to be seen whether the findings from these studies can be generalized and are applicable to other cities like NYC. Similar studies elsewhere could yield important advances in urban ecosystem theory while significantly adding to the growing empirical understanding of the dynamic interplay of patterns and processes that influence the functioning of urban ecosystems generally.

What We Still Need to Know

There is a high demand for research and testing in urban ecosystems, not only with respect to the ecological conditions of cities, but also in terms of putting into practice ecological knowledge in urban planning. We still need to know what it is exactly that we need to know.[34] Although in cities like NYC there are extensive databases of various sorts including infrastructure data layers in GIS, past vegetation studies scattered around the city, and weather data from local weather stations, most data are not of direct importance to ecologically oriented urban planning. Therefore, one clear need is for model projects to establish a framework, stating which data are essential and in what forms they should be made available. Likewise, we need to effectively measure the success, failure, and efficiency of planning efforts such as MillionTreesNYC. Only by actually analyzing goals, techniques, and results can we be sure that the guidelines for ecologically oriented urban development such as PlaNYC can be implemented in an optimum way. The above needs can really only be satisfied through long-term research, such as the ongoing studies in Baltimore and Phoenix.

Ecosystem science has historically dealt with non-urban areas, and many of the accepted ideas that dominate ecosystem science are not easily applied in urban settings. The need for testing of current theory is paramount to identifying the future research directions in urban ecology. This is also true of urban forest ecology. The urban forest ecosystem includes all flora and fauna (including humans) in a defined urban area.[35] This means that management of an area, such as an urban forest ecosystem has to plan for the sustainable interaction between human and nonhuman components of the system. The ecosystem approach employed in Baltimore and Phoenix has finally taken hold, and city managers are beginning to embrace an adaptive management approach that includes an underlying view of cities as human ecosystems. NYC Parks and Recreation, for example, is working

to employ an adaptive management approach through the various parks it is actively restoring and the ongoing ecosystem research it supports.

Ecological restoration, urban forestry, and greenspace management are all efforts that require not only technical information but also a comprehensive and integrated approach that fully accounts for the spatial and temporal distribution of benefits and costs of different actions. Any action in the system will affect the operation, or function, of the system, and various states will generate different spatial-temporal distributions of benefits and costs. MillionTreesNYC will therefore logically affect the urban forest ecosystem and, by extension, the entire human ecosystem of NYC. The Human Ecosystem Framework, originally developed by Gary Machlis, Jo Ellen Force, and William Burch, provides an entry point for integrating the human and nonhuman components of the city in a way that allows hypothesis generation regarding the interaction of these components.[36]

Urban Ecosystem Research in NYC

New York City is just beginning to initiate empirical urban ecosystem research that is large in scale and interdisciplinary—that joins the sociological and ecological study of the city as an ecosystem. A year after the symposium to set a research agenda for MTNYC, the New School hosted another symposium, the MillionTreesNYC, Green Infrastructure, and Urban Ecology Research Symposium, in 2010, sponsored by MTNYC and multiple partners.[37] More than 200 attendees joined more than 60 national and international presenters during two days to present research results and discuss new pathways toward designing more sustainable cities. The event provided an important platform for networking, generating new collaborations between attendees, and, we hope, will generate novel research both in NYC and other urban ecosystems.

A collaborative effort bringing together Columbia University, New Jersey's Science and Technology University, the U.S. Forest Service, NYC Parks Department, the New School's Tishman Environment and Design Center, and others began examining the dynamics of forest stewardship activity and its impact on urban ecosystems. Funded by the National Science Foundation (NSF) in 2009, the study is part of the NSF ULTRA-Ex, or Urban Long-Term Research Areas Exploratory Award program.[38] Sixteen other studies in cities across the United States were also funded by NSF ULTRA-Ex for a total investment of nearly $5 million into urban ecosystem research, which provides an encouraging step to-

ward furthering our understanding of urban systems and potentially provides a basis for city-to-city comparisons.

Academic researchers joined forces with NYC Parks in 2008 through the MTNYC Advisory Board's Research and Evaluation Subcommittee to begin to assess the ecological outcomes of MTNYC. This resulted in a partnership among NYC Department of Parks and Recreation's Natural Resources Group; the New School's Tishman Environment and Design Center; Columbia University's Department of Ecology, Evolution, and Environmental Biology; and Yale University's School of Forestry and Environmental Studies to assess the short- and long-term impacts of MTNYC's forest restoration efforts on the structure and functioning of NYC urban forest ecosystems. Some of the questions the research will address over the next years in order to provide baseline scientific data to inform adaptive forest management in NYC include:

- What planting strategies should NYC park managers employ to maximize particular ecosystem functions in urban forests?
- How will newly forested urban land affect invasive species dynamics at the scale of the park, city, and the region?
- Will current forest management practices affect biodiversity?
- How long will it take for the forest canopies to close under different management practices?

Researchers were able to leverage the MTNYC campaign to reorganize volunteer tree-planting events into a structured long-term experimental study of plot treatments. By studying vegetation and soil dynamics in a large number of heterogeneous sites across the city, researchers will build a more comprehensive picture of the ecological dynamics of forests in NYC. Long-term study of forest restoration and regeneration such as this is critical to understanding NYC as a human ecosystem, because so much of the system is forested. The plot-based, ground-scale approaches will help evaluate the ecological outcomes of the reforestation of the city, but will also provide recommendations for future design and forest management strategies at multiple scales.

Conclusion

PlaNYC is an ambitious effort to make NYC more sustainable by the time it is expected to exceed 9 million residents in 2030. MillionTreesNYC, one of the

PlaNYC initiatives, has already achieved some success, planting more than 300,000 trees in less than three years. Whether or not planting trees succeeds in generating the kinds of ecological, economic, and social benefits that are expected remains to be seen. To judge the effectiveness of the urban sustainability improvements projected in PlaNYC requires well-designed scientific research. Urban ecological research in New York City must take a front seat in the challenge to make the city more sustainable. This will require government and private foundations to sponsor research over short and long time frames in order to provide the fundamental science that policy makers, managers, and practitioners need in order to make decisions that can achieve the noble sustainability goals set forth in PlaNYC. Urban planners and designers alike will need to commit to making use of available ecological science.

Urban ecology is most useful when it is applied to the problems it was originally designed to address. Urban ecosystem research, well demonstrated in the Baltimore Ecosystem Study, has the potential to provide important data on how best to maximize various functions urban dwellers desire from the green infrastructure of the city, but only if urban planners commit to doing the hard work of understanding and incorporating ecological research results into their creative enterprises.[39] Similarly, urban ecologists must commit to interdisciplinary dialogues that make use of the storehouse of knowledge designers and practitioners working in urban areas already have. As global climate change, urban population growth, economic upheaval, and other threats provide new challenges to New Yorkers, transforming NYC into an "ecological city" depends on building a strong coalition of sustainability minded city officials, urban planners, green infrastructure managers, academic researchers, and motivated citizens to leverage the limited resources we have now to create a sustainable future New York City.[40]

Notes

1. More detail on PlaNYC 2030 can be found at www.nyc.gov/planyc2030.
2. Information on MillionTreesNYC is accessible at www.milliontreesnyc.org/.
3. Owen, D. 2009. *Green Metropolis: Why Living Smaller, Living Closer, and Driving Less are the Keys to Sustainability*. Riverhead Books, NY.
4. American Public Transportation Association Factbook accessible at: http://apta.com/resources/statistics/Documents/FactBook/APTA_2010_Fact_Book.pdf.
5. View a description of the U.S. Forest Service's mapping of stewardship organizations, called STEW-MAP, at http://nrs.fs.fed.us/nyc/focus/stewardship_mapping/. A recent article

describing STEW-MAP is: Svendsen, E. S. and L. K. Campbell. 2008. "Urban Ecological Stewardship: Understanding the Structure, Function and Network of Community-Based Urban Land Management." *Cities and the Environment*, 1(1): 4, accessible at http://escholarship.bc.edu/cate/vol1/iss1/4/.

6. See the chapter by Cohen and Obadia in this volume.

7. For more information on NYC's green infrastructure see the NYC Parks and Recreation's Natural Resources Group at: www.nycgovparks.org/sub_about/parks_divisions/nrg/nrg_home.html.

8. The U.S. Environmental Protection Agency provides an overview of the urban heat island effect at: www.epa.gov/heatisld/.

9. For a concise overview of the mitigation possibilities for the UHI in NYC see Cynthia Rosenzweig, William Solecki, Lily Parshall, Stuart Gaffin, Barry Lynn, Richard Goldberg, Jennifer Cox, and Sara Hodges. 2006. "Mitigating New York City's Heat Island with Urban Forestry, Living Roofs, and Light Surfaces." Presentation at 86th American Meteorological Society Annual Meeting, Jan. 31, 2006, Atlanta, Georgia. Article is available at: www.giss.nasa.gov/research/news/20060130/103341.pdf.

10. The New York City Panel on Climate Change, which consists of climate change and impacts scientists, and legal, insurance, and risk management experts, was charged by NYC Mayor Michael Bloomberg with serving as the technical advisory body for the mayor and the New York City Climate Change Adaptation Task Force (the "Task Force") on issues related to climate change, impacts, and adaptation. The full Climate Risk Information report can be accessed at: www.nyc.gov/html/om/pdf/2009/NPCC_CRI.pdf.

11. The *New York Times* article describing the 2009 storm more fully is available at: http://cityroom.blogs.nytimes.com/2009/08/19/storm-topples-scores-of-trees-in-central-park/?scp=2&sq=new%20york%20storm%20trees%20down%202010&st=cse.

12. The *New York Times* article describing the 2010 storm more fully is available at: www.nytimes.com/2010/03/15/nyregion/15storm.html?scp=8&sq=new%20york%20storm%20trees%20down%202010&st=cse.

13. For more on sea level rise in NYC, view the Union of Concerned Scientists full report at: www.climatechoices.org/assets/documents/climatechoices/new-york_necia.pdf. The Sea Level Rise Task Force for NYC is studying the effects of predicted sea level rise and how to adapt at: www.dec.ny.gov/energy/45202.html. To view a simple map-based simulation for sea level rise in NYC, go to: www.climateatlas.org/nycslr.html or a global map is available at: http://flood.firetree.net/. See also NASA's website for predicted sea level in NYC at: www.nasa.gov/mission_pages/hurricanes/archives/2006/sealevel_nyc.html.

14. U.S. Census Bureau, accessible at: www.census.gov/population/www/censusdata/density.html.

15. PlaNYC 2010 Progress Report, available at: www.nyc.gov/html/planyc2030/downloads/pdf/planyc_progress_report_2010.pdf.

16. American Lung Association 2010 report accessible at: www.stateoftheair.org/2010/city-rankings/most-polluted-cities.html.

17. US Geological Survey Water Cycle and Evapotranspiration page: http://ga.water.usgs.gov/edu/watercycleevapotranspiration.html.

18. For details on the analysis of the of the city's forest using the U.S. Forest Service's Urban Forest Effects Model (UFORE, now called iTREE), see Grove, J. M., J. P. M.

O'Neil-Dunne, K. Pelletier, D. J. Nowak, and J. Walton (2006). A Report on New York City's Present and Possible Urban Tree Canopy. Prepared for Fiona Watt, Chief of the Division of Forestry & Horticulture. New York City's Department of Parks & Recreation, Northern Research Station, USDA Forest Service. Also see the iTREE urban forest analytical software available at: .www.itreetools.org/.

19. Nowak, D. J., R. E. Hoehn, D. E. Crane, J. C. Stevens, and J. T. Walton. 2007. Assessing urban forest effects and values, New York City's urban forest. Resource Bulletin NRS-9. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA.

20. Nowak, D. J., R. E. Hoehn, D. E. Crane, J. C. Stevens, and J. T. Walton. 2007. Assessing urban forest effects and values, New York City's urban forest. Resource Bulletin NRS-9. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA.

21. Nowak, D. J., R. E. Hoehn, D. E. Crane, J. C. Stevens, and J. T. Walton. 2007. Assessing urban forest effects and values, New York City's urban forest. Resource Bulletin NRS-9. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA.

22. Information on the New York City Community Air Survey is accessible at: www.nyc.gov/html/doh/html/eode/nyccas.shtml.

23. STRATUM, an early model developed by researchers at the University of California at Davis and the U.S. Forest Service to assess the economic value of trees is now part of the iTREE software suite. Information on STRATUM is available at: www.fs.fed.us/psw/programs/cufr/stratum.shtml.

24. Trees for Public Health priority planting areas for MTNYC can be viewed at: www.milliontreesnyc.org/html/million_trees/neighborhoods.shtml.

25. For more information, see the MillionTreesNYC website at: www.milliontreesnyc.org/.

26. NYC Street Tree Mortality Study results were presented at the 2010 MillionTreesNYC, Green Infrastructure, and Urban Ecology Research Symposium by NYC Parks scientists. The abstract is available here: http://milliontreesnyc.org/downloads/pdf/symposium_research_abstracts.pdf.

27. You can download the full 2009 workshop report at: www.milliontreesnyc.org/research.

28. Egerton, F. N. 1993. "The History and Present Entanglements of Some General Ecological Perspectives," pp 9–23. In McDonnell, M. J. and S. T. A. Pickett (eds.). *Humans as Components of Ecosystems: The Ecology of Subtle Human Effects and Populated Areas*, Springer-Verlag, New York, NY; McDonnell, M. J. and S. T. A. Pickett. 1993. *Humans as Components of Ecosystems: The Ecology of Subtle Human Effects and Populated Areas*. Springer-Verlag, New York, NY; Holling, C. S. 1994. "New Science and New Investments for a Sustainable Biosphere," pp. 57–97. In A. Jansson (Ed.). *Investing in Natural Capital: The Ecological Economics Approach to Sustainability*. Island Press, Washington, D.C.; Cronon, W. 1995. "The Trouble with Wilderness; Or, Getting Back to the Wrong Nature," pp. 69–90. In Cronon, W. (Ed.). *Uncommon Ground: Toward Reinventing Nature*. Norton, New York, NY.; Alberti, M., J. M. Marzluff, E. Shulenberger, G. Bradley, C. Ryan, and C. Zumbrun-

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37. Details on the MTNYC Research Symposium can be found at http://milliontrees nyc.org/research. Also see the journal *Cities and the Environment* at http://escholarship.bc .edu/cate/ for a special journal issue of the symposium, anticipated publication in 2011.

38. The National Science Foundation ULTRA-Ex Program details are accessible at: www.nsf.gov/pubs/2009/nsf09551/nsf09551.htm.

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